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FRAMEWORK FOR EVOLUTIONARY DEVELOPMENT OF AN AUTONOMOUS EXPERT SYSTEM FOR ACOUSTICALLY IDENTIFYING CLASSIFICATIONS OF VESSELS

Robert M. Hayashi

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FRAMEWORK FOR EVOLUTIONARY DEVELOPMENT OF AN AUTONOMOUS EXPERT SYSTEM FOR ACOUSTICALLY IDENTIFYING CLASSIFICATIONS OF VESSELS

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January 1989

Approved by R.S. Walker H/Signal Processing Section

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Abstract

The development of an autonomous expert system for identifying vessel classifications from passive acoustic spectrograms is the ultimate goal of Artificial Intelligence (AI) work ~~being conducted at DREA~~. An evolutionary development is a natural approach since application of AI technology has not yet been placed on an 'engineering' basis and development of complex systems is to some extent still a research endeavour. A framework consisting of a series of practically achievable assistant systems, in which a human operator and a computer share the identification task to varying extents, is proposed as a research-oriented basis for the development of a completely autonomous system.

Keywords: Signal processed acoustic data, Canada.

SOMMAIRE

Une expérience en intelligence artificielle (IA) en cours au CRDA vise la mise au point éventuelle d'un système expert autonome pour l'identification de la classe d'un navire à partir de spectrogrammes acoustiques passifs. Le développement évolutif constitue une approche naturelle, puisque du point de vue technique, les applications de la technologie de l'IA ne sont pas encore à un stade suffisant et que le développement de systèmes complexes reste encore une activité de recherche fondamentale. On propose comme base de recherches, en vue de développement d'un système autonome complet, un système cadre formé d'une série de systèmes de soutien réalisables à l'heure actuelle; un opérateur humain et un ordinateur partageront à divers degrés les tâches d'identification.

Contents

Table of Contents

1 **Introduction** 1

2 **Delineation of Interim Development Systems** 3
- 2.1 Identification Process as a Basis for Defining Systems 3
- 2.2 Role of User-Friendly Interface 4

3 **Concepts of Assistant and Autonomous Artificially Intelligent Systems for Identifying Classifications of Vessels** 6
- 3.1 Basic Assistant System 6
- 3.2 Simple Assistant System 8
- 3.3 Advanced Assistant System 9
- 3.4 Sophisticated Assistant System 11
- 3.5 Artificially Intelligent Systems Ranging from Simple Assistant to Completely Autonomous 12
  - 3.5.1 Simple Assistant Artificially Intelligent Systems 12
  - 3.5.2 Autonomous Artificially Intelligent Systems 14

4 **Intelligent Analysis Aids** 16

5 **Concluding Remarks** 18

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1 Introduction

The work of the Computer Aided Detection (CAD) Group at the Defence Research Establishment Atlantic (DREA) is currently focussed on the development of computer-based systems for identifying classifications of vessels represented on passive acoustic spectrograms. Spectrograms present signal processed acoustic data, mainly as narrow-band features on frequency-time plots in which intensities only appear qualitatively. Artificial Intelligence (AI) provides technology for computerization of some decision-making tasks involved in identification through development of expert systems. However, the computerization of the identification process presents many practical problems for the construction of an expert system.

DREA's expertise gained in the AI field by conducting research studies, by improving and supporting a knowledge representation package [Dent and Smith 1983; Smith and Friedland 1980] and by developing a 'toy' expert identification system [Maksym 1983] led to the following important realization. The current state of technology of AI, signal processing and computer hardware makes the building of a completely autonomous expert identification system unfeasible in the short term, if not in an absolute sense, then at least in a practical sense. As will become obvious as the discussion proceeds, a completely *autonomous* expert system for identification of classifications of vessels from acoustic spectrograms is much more complex than a *conventional* expert system. Most conventional expert systems do not possess the capability for extracting from observations, information that the system requires for making decisions. MYCIN [Shortliffe 1976] is a well-known example of such a conventional system. Acquisition of identification information from observations presented as acoustic spectrograms is a particularly difficult task to automate.

A realistic, immediate and practical goal is the construction of a system that assists a human to conduct an identification. Such an assistant system would be a computerized system which either an analyst or operator can use to conduct spectrogram analyses more effectively, or at least more efficiently than by conventional means. An assistant system can be categorized by the type and degree of assistance which it is capable of providing the user. In fact, use of the term analyst and operator implies some distinction in the capability that the computer must contribute. An analyst is a person who is highly qualified to conduct identification. An operator is a person who lacks in-depth knowledge required to conduct identification and therefore must rely on the computer to provide some of the intrinsic resources. Sophisticated identification capability cannot be implemented entirely through conventional computational techniques. The system must therefore be based on AI. Taking a perverse AI view, since a completely autonomous Artificially Intelligent system is not practical, one might claim that an assistant system is an Artificially Intelligent system which requires human assistance to conduct a classification identification. However, the essential need for a genuine partnership can be captured through the use of the term *hybrid* assistant system. An hybrid assistant system is a computer-human system in which an operator is a critical and integral part of the system. The human and the computer conduct identifications cooperatively and interactively. The construction of hybrid systems raises the matter of task sharing, which is part of a larger issue, that of specifying the systems in a formal way. Obviously a range of hybrid assistant systems would be possible, depending on the extent of participation of the operator in the identification process.

This paper takes a broad development perspective and addresses the goal of realizing an autonomous system. The overall development strategy adopted is the well-recognized evolutionary approach. The ultimate system is to be achieved through construction of a series of hybrid systems in which the computer takes a gradually increasing role in the information management and processing that constitutes the identification process. The key to managing and controlling evolutionary development is to devise a framework of significant intermediate systems that naturally and incrementally introduce improvements needed to achieve the ultimate system. In effect, the systems represent intermediate development goals. Otherwise with good fortune, reasonable intermediate systems would just evolve and interim goals only become apparent after the fact. In the worst case, the development will tend to deteriorate to the 'monkey and new novel' approach[1]. Furthermore, the interim systems should play another important role in a development program. They should serve as a medium for examining and understanding critical-path problems, for formulating solutions for advancing development and for exploring ways to overcome technological deficiencies.

Establishment of a useful framework can obviously be very difficult but a framework is fundamental to the effective application of an evolutionary approach in many spheres of development. The main requirement is to conceive realistic systems as achievable, intermediate, development targets. Although it is difficult to define systems precisely as practical models at each stage of an evolutionary development process, nevertheless the presentation of some concreteness early in the development work would be valuable. Initially, in order to devise a framework prior to the initiation of development, it is necessary to adopt an informal approach and describe systems loosely through functional characteristics rather than define them through specifications. Approaching development in a pre-planned evolutionary manner enhances the possibility of providing a series of practical working demonstration systems throughout the development program.

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[1] If an infinite number of monkeys began typing, after a possibly infinite length of time a new novel may be produced.

2 Delineation of Interim Development Systems

In order to conceptualize systems that would serve as development milestones, it is helpful to be able to follow some general guiding principles. The principles should address issues that strongly influence the characteristics of systems. Some of the issues are obvious. What sort of mutual assistance should the computer and operator provide? What kind of operator (experienced or novice) should be designed into the system? Should the system be directed to applications that require a real-time capability as opposed to a post-analysis capability? What level of performance, compared to a recognized expert, must the system have? Not all the issues need be explicitly exposed here.

An overall principle to guide the creation of a developmental framework is to address the easier application(s) and use any success to advance to the more difficult case(s). However, the specification of practical systems should not be determined only by the requirements of the (potential) application. It is necessary to consider the limitations imposed by current and probably advancing technology. Thus, for initial development systems the computer should assist the operator by handling tasks based on routine information processing, as opposed to processing that demands explicit and sophisticated decision making. In more advanced systems the computer can undertake decision making that can be implemented heuristically or algorithmically. The implication is that the first few systems should perhaps involve an expert. Succeeding systems can involve reasonably trained operators rather than an expert since it will be difficult for the computer to assist an expert in significant ways. Advanced systems should be able to function with untrained users. What does this mean for the definition of hybrid systems? The presence of even a slightly trained operator opens up great possibilities for the design of a total system since humans possess highly sophisticated visual and decision-making capabilities compared to computers. It is sensible to apply those capabilities to aspects of the identification process that are difficult to computerize. The corollary implication is that use of totally untrained operators places unacceptable constraints on the definition of early development systems.

2.1 Identification Process as a Basis for Defining Systems

The advantage of flexibility introduced by modular construction for systems that need to be modified later requires no rationalization. However, in order to build a system in modular fashion a sufficient understanding of the identification process is an obvious prerequisite. An idea is to use the identification process as a framework for designing a series of systems, thereby making the process a unifying feature for all systems. Differences in the systems will be in details of implementation of the same overall identification strategy. A knowledge of the strategy used by experts to identify vessel classifications from spectrograms should serve as the foundation for detailing the identification process as a form of information management suitable for execution by a hybrid system. The strategy provides the basis for implementation of the control that the computer program must exercise over the operation of the whole system. A control scheme originated in that way can effectively serve a range of systems, even those with little or no ingrained AI capability. It will even be applicable to initial autonomous systems, although consideration should be given to the eventual creation of a computer-oriented strategy for a completely autonomous system. Obviously the strategy will dictate the requirement for various processing functions that must be installed in the system and the management of their use in a coordinated way. Thus the major distinction among systems will be the division of information processing responsibilities between the computer and the operator. In general, the degrees of software sophistication involved in a system depends on the processing that the computer is tasked to do and it therefore determines a system's capability for autonomous operation.

In order to use the identification process as a basis for establishment of a framework for system development, it is important to understand that the overall identification process can be considered to consist functionally of two sub-processes. The first is analysis of the spectrogram to detect acoustic features, which supports the second, the inferring of a classification identification. In an effectively operating identification process the two sub-processes are executed in an inter-dependent manner. That effectiveness arises from implementation, at a general level of information processing, of knowledge-guided operation, a very important AI principle. Without going into a detailed discussion of the identification process, it can be pointed out that the two sub-processes provide a natural division for the allocation of the identification task, at least for early development systems. The operator can concentrate on analysis and the computer software can be responsible for making inferences. Some analysis aids that are proposed as a mechanism for providing a user-friendly interface in assistant systems promote the integration of the two sub-processes.

This paper concentrates on delineating systems in a general way. Its intent is not to delve into design and specification details. Therefore, despite the important role that analysis tools and aids play in evolutionary systems, the capabilities provided by analysis devices will only be characterized in very general ways. Their detailed descriptions and discussion of their functionalities are presented elsewhere [Hayashi 1988].

2.2 Role of User-Friendly Interface

An extremely important consideration for hybrid assistant systems is the operator-computer interface. The interface must be operator-friendly and must fully apply the potential for *interaction* between the operator and computer to the identification process. The benefits of promoting interactive participation in conducting identification should have a strong influence on system definition.

There are two generic types of expert systems, rule-based and frame-based. They differ in the form of knowledge representation predominantly used. A rule-based system has a simpler and possibly a more standardized knowledge base as well as information processing control structure than a frame-based system. For rule-based systems, domain knowledge is embedded in rules. That knowledge includes both factual and control information. The selection of an overall generic strategy, such as backward chaining, more or less provides an identification process control mechanism and is therefore a definitive decision in the design of a system. The intimate intermingling of factual and control information can be minimized in frame-based systems because a knowledge base generated using frame representation is intrinsically created in a modular way. This makes it easier to trace and understand the way in which the system arrives at an inference. The control mechanism of a system in which knowledge is organized into frames may be based on a basic AI strategy, such as hypothesize-and-test, but selection of a generic strategy is not a truly definitive step in the design of a system. Control-related issues such as whether, where and how to distribute control knowledge will significantly influence the design of the system. However, it is important to realize that an information retrieval system can be easily implemented when a knowledge base is represented as frames. The CAD Group made an early decision to build frame-based Artificially Intelligent systems.

The interface is the medium for communication between the computer and operator. For maximum benefit, the communication should occur in both directions. The concept of hybrid systems proposed here is based to a critical extent on the use of analysis aids for creating the required interface. It will become evident later that unconventional analysis aids, especially *active* ones that promote *bi-directional* flow of information play a key role in systems that constitute the development framework. The aids can be looked upon as devices that make it easy for the operator to help the computer and vice versa. Therefore they provide an elegant way of covering up the inadequacy of the state of development of AI and signal processing technology for building a completely autonomous expert system for the identification of vessel classifications. An Artificially Intelligent identification system requires more than just expert system technology. Technology from other AI areas, for instance pattern recognition activities which are being studied under computer vision research, has a vital role to play in a completely autonomous Artificially Intelligent system. At the present time, some of that technology can only be applied under very constrained and ideal situations.

There is good justification for strongly basing an evolutionary development approach on computer-based analysis aids. Computer versions of conventional analysis aids will provide an analyst with a reassuring link to the traditional identification procedure when he or she undertakes the transition from conventional to computerized analysis. Analysis aids can have capabilities not available in conventional analysis tools. If early computerized systems incorporate analysis aids, those systems will still be able to offer some improvements even if problems which require some research for their solution prevent significant AI from being incorporated at an early development stage. AI of course offers the greatest potential for major innovations. Analysis aids can be developed in such a way as to function as devices for entering acoustic information from spectrograms into a computerized identification system. The aids provide a very natural way for analyzing spectrograms and inputting qualitative and quantitative information into a dynamic knowledge base. The knowledge base can be considered to consist of a static portion and a dynamic part. The static part contains pre-defined knowledge relevant to any identification whereas knowledge pertaining to a specific identification, generated at run-time, is dynamic knowledge. AI can be introduced incrementally into a system based on analysis aids, all the while maintaining a usable system. AI can be incorporated by replacing aids with program modules which possess the same functional capability as the combination of the aids and the operator's contribution. A realistic assessment would indicate that complete replacement, with practical software modules, of all the functions performed by the combination of the operator and most of the analysis aids is no trivial task. If that task proves to be too difficult or too long term to achieve, the option exists for replacing with software, only selected aspects of the operation of some aids, aspects which rely for execution on more routine intellectual participation by the operator. Without the use of analysis aids, it will not be possible to build practical Artificially Intelligent systems for a long time.

3 Concepts of Assistant and Autonomous Artificially Intelligent Systems for Identifying Classifications of Vessels

Although it might be tempting to by-pass some of the early systems in order to proceed to the construction of ones that present design challenges, there is merit in building even the simple ones. The early systems serve to introduce acoustic spectrogram analysts to possibly a novel way of conducting spectrogram analysis, to new systems and to new analysis aids. Any feedback provided by an operator may suggest modifications for succeeding systems. Except for the initial systems, each succeeding system should incorporate AI in ever increasing amounts.

3.1 Basic Assistant System

The simplest assistant system involves the computerization of the medium for conducting conventional spectrographic vessel identification. The computer merely provides an environment for conducting the identification. The analysis aids for such a simple system, a system devoid of AI, need only be electronic emulations of tools normally used in spectrogram analysis. Thus such a system would be a computer workstation which allows:

- a spectrogram to be selected for display,
- an harmonic set analysis tool to be used to extract information from the spectrogram,
- analysis information to be entered and maintained on an electronic worksheet,
- acoustic data handbook information about classification signatures to be accessed on-line,
- the state of the analysis to be viewed by displaying information from the worksheet, either on the workstation monitor or as a hardcopy.

One way of succinctly summarizing the general features of a system is by means of a block diagram. Figure 3.1 shows the concept of the Basic Assistant System in that form.

For the simplest system, the only analysis tool required is a Harmonic Set Analyzer. It will be primarily a computerization of the principle function provided by the conventional mechanical eleven point divider. The electronic worksheet [Gergley 1988] will provide for the storage of the information conventionally recorded on an analysis summary worksheet. A menu system should be employed to allow the user to call conveniently any of the capabilities listed above. On-line retrieval of acoustic information is one of them. The obvious way to implement that capability is through a data base system. However, that would not be the most efficient approach in this case since later AI-based systems would require essentially the same information in a knowledge base (KB). Therefore for an evolutionary system, the information base for implementation of on-line retrieval and the knowledge base should be one and the same. That retrieval capability should obviously involve a knowledge base approach to representation.

A convenient means for entering and displaying worksheet information must be provided. The method devised for this system should be interactive and be useful as well for follow-on Artificially Intelligent systems which will have to understand and use the entered information to make inferences. Therefore the vocabulary for filling the worksheet should be restricted even at this early stage. Input through menus is a friendly way for controlling information entry. Although not enumerated above as a primary system characteristic, it would be useful to be able to hardcopy the worksheet.

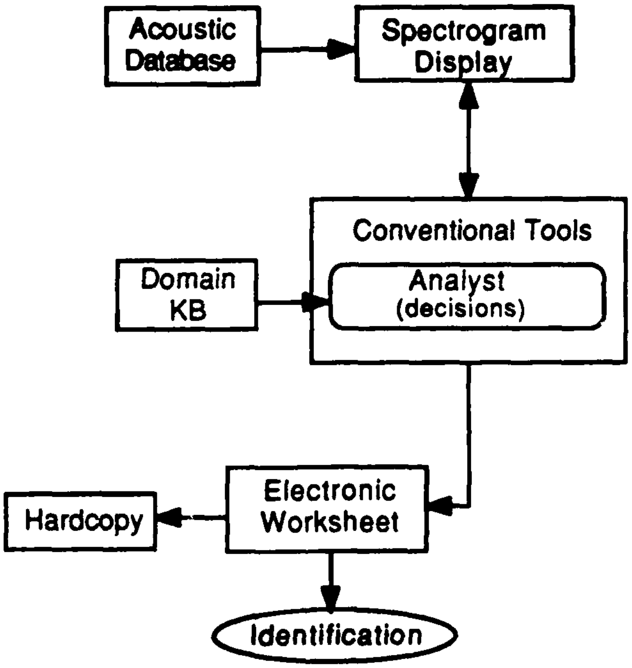

Figure 3.1: Basic Assistant System

This basic system will enable an analyst familiar with the conventional spectrogram analysis procedure to conduct an identification in the normal manner, essentially without training to learn about the capabilities offered by the computer. The analyst will be responsible entirely for the effective and orderly use of the capabilities provided by the computer and for all the decision making required to derive a vessel classification from a spectrogram. Therefore the system will not be particularly useful without a competent analyst and the system need not necessarily provide a great deal of supporting explanatory documentation.

A Basic Assistant System can be used to introduce an analyst to computerized analysis. It could also be exploited to gain an improved understanding of the classification identification process. One way to do that would be by having the computer internally record the sequence of steps that an experienced analyst follows in conducting identifications and then studying that kind of history for a representative set of spectrograms. The system will serve as a software foundation for the eventual construction of Artificially Intelligent systems.

3.2 Simple Assistant System

The Basic Assistant System could be upgraded easily to provide a greater capability for assistance by supplementing the computerized version of the basic conventional tool with non-conventional aids, aids which are based on the superior information handling capability of the computer. The aids will provide the analyst with sophisticated capabilities for examining the spectrogram to detect identification features [Hayashi 1988]. Many of the aids have no conventional counterparts. Therefore the system will require appropriate documentation that explains the functions of the various new aids, and possibly offer some words of advice as to how they might be exploited during the execution of a spectrogram-based identification.

In order to indicate the improved capability offered by the Simple Assistant System, some general comments about conventional tools and non-conventional aids will be presented. As noted earlier, the identification process can be regarded as being composed of two inter-related tasks. During examination of the spectrogram, the analyst must detect those acoustic features in terms of which signatures of classifications of vessels are specified. Vessel signature descriptions are not necessarily restricted to use of the fundamental spectrogram feature, the signal line[2]. They often involve higher level features which must be abstracted, usually from a combination of more basic features. The harmonic set is an example of an abstract feature. Information acquired during this task allows an analyst to proceed to the follow-on task, the interpretation of the observed information in terms of still higher abstractions, namely vessel classifications as well as physical component sources of acoustic signals. Interpretations conducted with application of knowledge about signatures result in classification conjectures and verification of an identification.

Conventional tools are used to abstract signature features from more basic spectrogram information. For example, a Harmonic Set Analyzer helps the analyst identify harmonically related signal lines. A Doppler Line Analyzer facilitates the calculation of vessel speed and range. Such tools are directly useful for conducting the analysis task but not the interpretation task. They merely respond in a passive way to control exercised by the operator. Non-conventional tools, the Line Analyzer is the simplest example, can truly be referred to as aids since they have been designed to actively respond during normal use, by reflecting to the analyst/operator a controlled and context-relevant interaction with knowledge base information. That is the reason for the importance of two way communication capability for active aids. Active aids are directly useful for assisting the interpretation task.

A complete explanation of active operation and context-relevant feedback of information requires some knowledge of unconventional aids. Since this discussion is concerned with an evolutionary development framework, a long digression will be avoided and only the following amplification is offered. Consider the Line Analyzer as a representative example of an active aid. One elementary way of applying it to the analysis of

[2] Actually the pixel is the most basic feature but signatures are specified in terms of abstract features such as lines and sets of lines. A line is a set of associated points that extends in the time direction at any frequency. Characteristics such as straight, wide, diffuse, central frequency, etc., that can be attributed to a closely aggregated group of pixels, establish appropriate high level descriptions for lines.

a spectrogram would be by sweeping the total frequency spectrum with the device icon which is overlaid on the spectrogram display. The device is operated through the use of the computer mouse since the device icon is the mouse cursor for the Line Analyzer. When the cursor designates a frequency which corresponds to the frequency of an identification-significant line of any classification, the Line Analyzer devised at DREA dynamically reports the name of the particular classification for which the frequency is important. The requirement is then to determine if the cursor coincides with a signal line under those special temporary static conditions. The responsibility for that decision concerning the frequency matching of a line with the icon still rests with the analyst. If a match occurs while the name of a classification is being reported, the aid has in effect suggested a potential identification. Other aids using the same principle can contribute more extensively to the interpretation task by essentially merging conjecture of a classification and verification. Therefore non-conventional aids help the analyst to perform the interpretation task, the task which is generally associated with the requirement for AI.

The Basic Assistant System can be upgraded to a Simple Assistant System by incorporation of non-conventional aids. This is illustrated in Figure 3.2

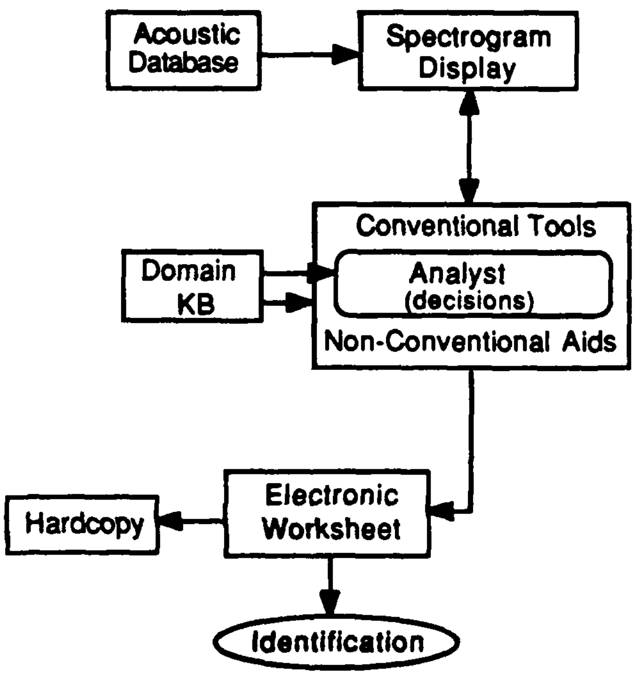

Figure 3.2: Simple Assistant System

The change from the foundation system is reflected in only one of the blocks.

3.3 Advanced Assistant System

In the systems described thus far, no guidance or help is imposed or offered to the analyst with respect to the logical usage of analysis tools during the course of an analysis. A system can be built in which the computer offers limited context-dependent guidance. The following is an example of context-dependent guidance. Suppose military intelligence information is available before the analysis has commenced. When that information, in the form of a suspected classification, is entered on the worksheet by the analyst, the computer's control program should appropriately restrict the scope of operation of the analysis aids. If the intelligence information indicates a diesel-powered vessel for example, the Line Analyzer should only be responsive to frequencies of identification-significant lines associated with signatures of diesel-powered vessels. The system would then be particularly tailored for confirming a vessel classification hypothesis and the aids would emulate the central feature of a goal or model driven system. A goal or hypothesis driven system uses an hypothesis to guide a search in a top-down direction but the Advanced Assistant System uses an hypothesis to confine the attention of an analyst to information in some restricted portion of the total knowledge base. The system therefore caters to the post analysis type of operation. However, it is worth pointing out that this system could be the basis for one used to conduct an identification during a surveillance mission. A process for generating an hypothesis would have to be devised as part of its 'front end'. Implementation of an hypothesis generation capability is more appropriate for an Artificially Intelligent system so this approach to computerization of the identification process will be incorporated in the description of a later system.

The Advanced Assistant System is represented by Figure 3.3.

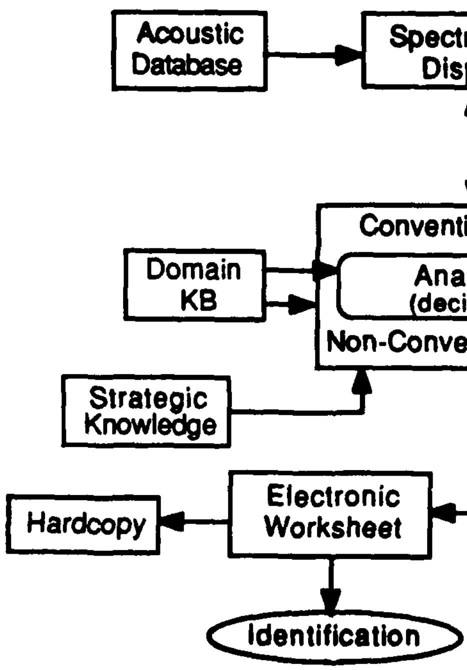

Figure 3.3: Advanced Assistant System

The improvement in this system arises from the automatic management provided by the computer over the use of the aids. That management is implemented internally at the control program level and is based on simple local strategy. This is a different strategy from the inference-oriented strategy required to build a sophisticated hybrid system in which the computer plays a dominant role. It is only for Artificially Intelligent systems that strategic knowledge becomes a major form of knowledge. Then it is global and much more complex since the strategy determines the way the identification process is implemented. It would be knowledge that is the basis for managing the selection of observed information and the application of factual knowledge.

3.4 Sophisticated Assistant System

A system slightly more self-sufficient than the Advanced Assistant System can be built by extending the capabilities of the analysis aids so that they become *intelligent* analysis aids. The concept of intelligent analysis aids is explained in a separate section. Essentially the aids take over some of the simple decision making. Therefore a system equipped with intelligent analysis aids can begin to exhibit intelligent behaviour. It should be noted that the decision making here relates to the analysis of the spectrogram and is concerned with extraction and entry of observed information into the system. It involves relatively routine decisions so that the decision making is more susceptible to algorithmic treatment. It is decision making that ultimately supports the inferring of a classification but it is not the major decision making that is directly and explicitly concerned with identification of a vessel classification. The analyst is still in control of making that inference. The identification decision is heuristic in nature and must be handled through the application of AI.

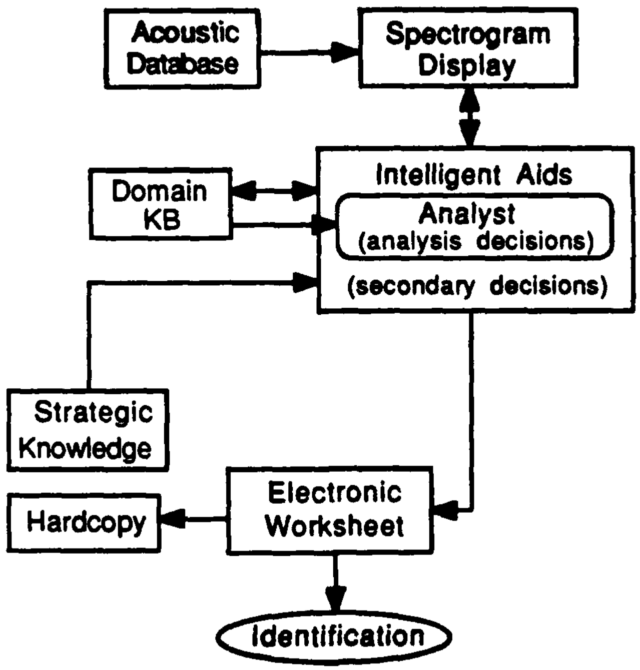

Figure 3.4: Sophisticated Assistant System

The improved capability of the Sophisticated Assistant System is indicated by Figure 3.4.

3.5 Artificially Intelligent Systems Ranging from Simple Assistant to Completely Autonomous

Somewhat arbitrarily an Artificially Intelligent system is defined to be one in which the computer software makes decisions directly concerned with identification of a classification. Such a system must be equipped with AI software which implements a strategy for heuristically inferring vessel classifications from acoustic information found on spectrograms. A Simple Assistant Artificially Intelligent System is one that possesses an identification strategy but is a system for which the detection and extraction of information needed to draw inferences about vessel classifications has not been computerized. A Simple Assistant Artificially Intelligent System could be regarded as an expert system of the conventional kind. The development of a Simple Assistant Artificially Intelligent system will enable an analyst (a highly trained individual) to be replaced with an operator (a less qualified individual). The operator will still play a significant part in the identification process by using the analysis aids to identify and enter acoustic information into the computer's dynamic knowledge base. The construction of the system remains relatively simple in that the computer does not have to possess the sophisticated capability to do such difficult tasks as detecting harmonic sets on a spectrogram and matching a signature pattern for a particular classification with a set of signal lines on a spectrogram. The matching is complicated since it must be done in an environment characterized by incomplete, uncertain and unknown information. A Simple Assistant Artificially Intelligent System could be developed into a more capable form of Artificially Intelligent System by further incorporating AI that would allow the computer to take over various functions performed by the combination of the operator and the different analysis aids.

A completely Autonomous Artificially Intelligent System is one that could analyze a spectrogram and provide a vessel classification without the operator being involved in any decision making. In such a system, all the analysis aids will be replaced with computer algorithms that examine the basic spectrogram data and extract information needed to deduce vessel identifications. Therefore such a system will, in principle, not even require a spectrogram display. AI technology from other than the expert system area will have to be incorporated into the Simple Assistant Artificially Intelligent System to reduce some of the responsibilities handled by the operator and eventually dispense with the operator's contribution. The AI content of a system will be reflected in its autonomous capability, its performance and its user friendliness. Development of a completely Autonomous Artificially Intelligent System may only be an idealistic goal at the present time. A more realistic goal is to develop a partially Autonomous Artificially Intelligent System.

3.5.1 Simple Assistant Artificially Intelligent Systems

The computer's role in the implementation of the identification process must be extended to the primary decision-making responsibilities handled by the analyst in previous systems. The Simple Assistant Artificially Intelligent System should be able to interpret acoustic features in terms of vessel classifications. In expert system terminology, it must have an inferencing capability. As implied earlier, an appropriate strategy for making inferences is conjecture and verification. Therefore a capability for generating vessel classification hypotheses and for confirming hypotheses should be incorporated by software. The capability must be a generalized one that allows the system to handle any spectrogram.

The computer program should be able to generate a knowledgeable guess at a probable classification, based on qualitative and quantitative information concerning either the appearance of the spectrogram or generic features that appear on it. The operator will still contribute by entering observations that the inferencing module requires in order to make educated classification guesses and eventually validate one. However, the computer must be given the capability to control hypothesis generation by specifying the actual information that the operator should seek or deduce by analyzing the spectrogram. The operator should be called upon, not so much to recognize high level features, but rather to see lower level information. The system should possess the apparent capability to infer high level features from low level information. However, the operator should not be given completely free initiative to select information for reporting, otherwise a separate small expert system might have to be built just to implement the hypothesis generation capability. Hypothesis generation should be implemented in a reasonably simple manner. It is anticipated that hypothesis generation will be based on a mapping table, analogous to a logical truth table, that projects characteristic sets of spectrographic information into different vessel classifications. Much of the information needed at this stage of identification would be qualitative, therefore use of a multiple choice menu for soliciting acoustic information through the assistance of the operator is recommended. The obvious kind of hypothesis that the system should be given the capability to generate from qualitative information would be generic vessel classifications rather than a more specific classification naming a particular type designation for a vessel. The difficulty of hypothesizing increases in proportion to the requirement to generate specific hypotheses.

An hypothesis is only a potential identification, although one with some substance since it is knowledge-based. However, it is normally based on use of only a fraction of the total observed information available, therefore it must be confirmed with additional information in order to convert it to an inferred identification. The inferencing module must be able to conduct the confirmation. It should use knowledge about the classification signature being confirmed in order to direct the operator to seek and provide the required verification information. The operator may use some of the aids mentioned explicitly for earlier evolutionary systems. However, for the Simple Assistant Artificially Intelligent System, those aids must be provided in an upgraded form so that they have full capability for creating knowledge base representations of acoustic features. That is the form in which acoustic information must be provided to the inferencing module.

A more sophisticated system without much greater autonomous capability might be one designed to handle multi-vessel spectrograms. Such a system should be able to hypothesize about the number of vessels represented on a spectrogram and be able to ascribe individual observed lines to separate sets corresponding to different, as-yet-unknown, vessels. Then the system can proceed to identify the classification of all the unknown vessels by processing the appropriate sets of lines separately with repeated application of essentially the same identification process. The ability to handle multi-vessel spectrograms will require the operator to input quite a bit of information from the spectrogram initially. For example, it may be necessary to look for and designate all lines which do not belong to sets of similar-looking lines.

In order to keep the operator informed and interested as an identification proceeds, it would be useful for the identification to proceed in stages, the stages being equivalent mechanistically to moving down a search tree of vessel classifications. At each stage, further input of information is requested and the new information triggers an update of the hypothesis concerning the classifications of vessels that could be the origin of the signal lines on the spectrogram. The identification therefore commences with a general classification and then the process attempts to refine it into more a specific classification identification. This stepwise refinement procedure copes in a natural way with the problem of uncertain and incomplete information on spectrograms. The identification terminates when the information available on any spectrogram will no longer allow a more specific classification to be found.

The Simple Assistant Artificially Intelligent System is represented by Figure 3.5. Most of the blocks have been retained in unchanged form since a new system is built from a previous one in an evolutionary development.

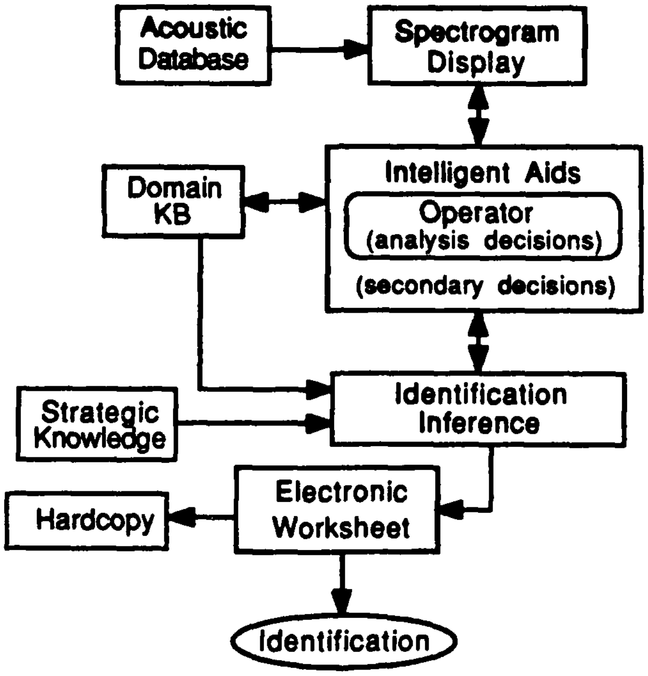

Figure 3.5: Simple Assistant Artificially Intelligent System

3.5.2 Autonomous Artificially Intelligent Systems

As suggested earlier, one way to proceed towards an Autonomous Artificially Intelligent System would be by replacing with software, the functionalities provided by the combined capabilities of each aid and the contributions of the operator to simpler assistant Artificially Intelligent systems. Such an enhanced system will conduct an identification essentially following the conventional process originated by human experts. There is no guarantee that a system built using that approach would be highly efficient since that identification process caters to the information processing capabilities of humans rather than computers. It may eventually be necessary to consider the possibility of other forms of autonomous systems. Then it would be sensible to examine other ways of information processing that would allow the identification process to be implemented in a computer-oriented way. That would require considerable research into topics as diverse as signal processing, pattern recognition, statistical estimation and neural networks to name but a few examples.

The Autonomous Artificially Intelligent System, as illustrated in Figure 3.6, does not involve an operator as part of the system. Furthermore, a sophisticated autonomous system should probably be able to extract acoustic features directly from acoustic data rather than through a spectrogram. The system should be able to justify, through an explanation module, any inference that it makes. However, in order to present an explanation in a way understandable to a system user, it may be necessary to make references to the familiar acoustic spectrogram.

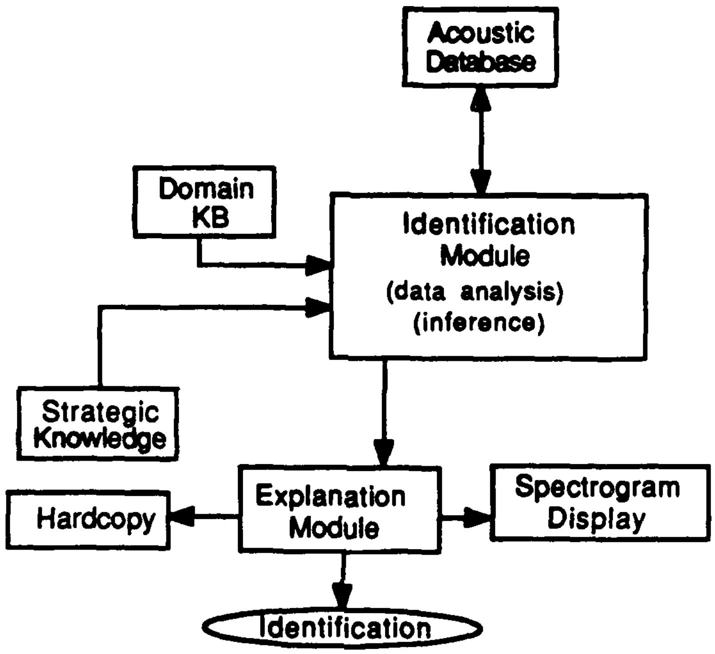

Figure 3.6: Autonomous Artificially Intelligent System

4 Intelligent Analysis Aids

Analysis aids, whether they be conventional or non-conventional, are based on the decision-making capabilities of the user. For example, a mechanical divider or even a computer-version of an Harmonic Set Analyzer is a tool only because the analyst uses them to identify harmonic sets. The analyst decides when a set of signal lines and/or a sufficient number of signal lines lie at the harmonic positions designated by the tool. Consecutive harmonic members of a set may not all be present as signal lines. Therefore the operator is burdened even with the task of indicating which signal lines belong to a certain set if it is important to record that kind of information. Even that seemingly simple task requires a sophisticated although possibly mundane decision-making capability.

An *intelligent* analysis aid is an aid that can take over some of the decision-making functions that the operator must exercise in using a particular aid. A couple of examples of how analysis aids could be made intelligent, in a limited way, should make this concept concrete. It is appropriate to select examples concerned with line detection and line description since the two topics are complementary and lines are a basic feature of spectrograms. Both examples present ample scope for the application of AI principles.

A simple intelligent analysis aid might be one that couples a line-detecting algorithm with the Harmonic Set Analyzer. After an harmonic set has been identified by the operator with the use of the Harmonic Set Analyzer, it is necessary for the operator to designate signal lines that are actually present in the set. The Harmonic Set Analyzer allows harmonic lines that have been detected to be marked on the spectrogram. Marking is a way of helping the operator to keep track of the state of analysis. For an Harmonic Set Analyzer designed for use in assistant Artificially Intelligent systems, the marking procedure also allows each set detection to be recorded in the dynamic knowledge base of the system by the creation of individual information representations of harmonic sets. From that perspective, it is useful to register all the line members present in any particular harmonic set. However, the use of knowledge of an identified harmonic set in the identification process may not necessarily require all the members of any set to be entered into the internal information representation of the harmonic set. A case in point would be an harmonic set which is identified and attributed by the operator as being emitted by a particular vessel component. For such a set it might be useful to know the fundamental frequency, the first few harmonics present, the highest-frequency harmonic observed, any intensity reinforcement patterning and a description of a typical member line. The Harmonic Set Analyzer assists the operator in entering harmonic lines by designating in turn each harmonic position so that if a corresponding signal line is present its existence can be recorded by merely clicking a mouse button. A line-detecting algorithm would relieve the operator of the chore of deciding on the presence of signal lines. By operating the Line Detector coupled to the Harmonic Set Analyzer, the complexity of design of a stand-alone line-detecting algorithm can be reduced. The Harmonic Set Analyzer will specify to the Line Detector the frequency locations at which to look for signal lines so that the Line Detector does not have to be capable of completely independent operation. The performance of the Line Detector can be improved by relying further on interactive operation. For example, the Harmonic Set Analyzer can be designed to allow the operator to provide the location of a typical line so that the Line Detector can analyze the typical harmonic line first. In any event, the Line Detector can set its detection controlling parameters for high speed and efficient performance on other lines, based on the first successful detection of a set member. Degradation of lines with increasing harmonic numbers can obviously be catered for if necessary, with the penalty of increased complexity. Line detection could thus be conducted in a knowledge-directed manner. A Line Detector will be the basis for making not only the Harmonic Set Analyzer into an intelligent analysis aid but can also be applied to upgrade other aids.

The Line Analyzer allows representations of signal lines to be created as part of the dynamic knowledge base. The representation for any designated signal line is automatically given one characteristic property, its frequency. Furthermore, the Line Analyzer uses a menu system to induce the operator to describe lines more fully. Therefore lines can be described in terms of standard symbolic descriptors for attributes considered significant for identification of lines. Examples of significant attributes are: intensity, bandwidth, stability, etc. Examples of standard descriptors are: medium, narrow, weak, etc. Software that determines such line attributes autonomously is required in order to make the Line Analyzer an intelligent analysis aid. A line-characterizing algorithm should examine the data points that fall along the frequency location of a line and be able to characterize the distribution of points in terms of high-level, line description parameters, such as intensity, diffuseness, etc. A crude idea is offered as illustration of how a Line Characterizer might measure intensity. The algorithm might analyze the data normally used in plotting a spectrogram and base the intensity on the number calculated by summing the measured intensity levels of all the points on a line and dividing the sum by the time-frequency area occupied by the line. The abstraction of high level descriptions is important since, at least for now, it will be such descriptions that will be used by Artificially Intelligent systems to draw inferences and to correlate signal lines on a spectrogram with lines that comprise signatures of particular vessel classifications. For example, the system may use similarities or an ordered change in line descriptions among a group of lines as a basis for identifying lines that do not belong to a set.

5 Concluding Remarks

An evolutionary approach is natural for the development of a complicated system or one that lies at the edges of technological advances. Such an approach is proposed in order to develop an expert system for the autonomous identification of vessel classifications from acoustic spectrograms. Within the constraints imposed by current signal processing and AI technologies and the state-of-the-art of acoustic identification of vessel classifications, the autonomous system must be considered an ultimate long-term goal. However, partially autonomous Artificially Intelligent systems are practical and useful development goals. Such systems, not unlike conventional expert systems, initially require the incorporation of an operator as part of the system in order to handle difficult-to-computerize information processing and decision-making tasks. Further development would be directed at weaning the operator out of the system.

A series of computer-based systems ranging from a basic computer environment for conducting identifications, through hybrid assistant systems, to a nearly autonomous Artificially Intelligent system is proposed as a framework for guiding the orderly development of practical Artificially Intelligent vessel classification identification systems. Initially, the key to computerization of the expert's identification process (which embeds an heuristics-based strategy) in the form of a practical system rests on mutual and interactive assistance between an operator and a computer. The characteristics of those intermediate systems are outlined and discussed.

The overall approach taken in conceiving and functionally characterizing the intermediate systems involves considering the identification process as two sub-processes: detection and extraction of acoustic features from the spectrogram, and inferring an identification. That provides a natural way of sharing the identification tasks between the computer and the operator. The computer is primarily responsible for making inferences in simple Artificially Intelligent systems, whereas the operator participates in information extraction. The framework is therefore predicated on the use of analysis aids to allow a friendly and significant interaction between the computer and the human operator. Aids with the capability for feedback of knowledge base information allow the computer to participate in both aspects of the identification process. Intelligent aids will take over some of the routine and potentially tedious decision making normally handled by humans in simple assistant systems.

The attainment of a completely autonomous system can be approached through replacement by software of the functionalities that the combination of the aids and an operator's intellectually-based contributions provide to partially autonomous systems.

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The development of an autonomous expert system for identifying vessel classifications from passive acoustic spectrograms is the ultimate goal of Artificial Intelligence (AI) work being conducted at DREA. An evolutionary development is a natural approach since application of AI technology has not yet been placed on an 'engineering' basis and development of complex systems is to some extent still a research endeavour. A framework consisting of a series of practically achievable assistant systems, in which a human operator and a computer share the identification task to varying extents, is proposed as a research-oriented basis for the development of a completely autonomous system.

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